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ABSTRACT—Responses of small mammals to management of roadsides in south central Minnesota were examined from August-October in 1980 and 1981. The Minnesota Department of Natural Resources established and maintained vegetation along portions of these roadsides by planting *Bromus inermis* and *Medicago sativa* as nesting cover for ring-necked pheasants (*Phasianus colchicus*) and with infrequent mowing. Landowners or state and county transportation departments maintained other roadside areas by frequent mowing of native vegetation. Mowing of roadsides had a negative effect on abundance of *Blarina brevicauda, Peromyscus leucopus, Microtus pennsylvanicus,* and *Mustela erminea* during both summer and autumn and on abundance of *Peromyscus maniculatus bairdii* during late summer. In contrast, mowing had a positive influence on abundance of *Mus musculus* in roadsides planted with *B. inermis* and *M. sativa* during summer and autumn. Roadsides planted with *B. inermis* and *M. sativa* apparently increased the number of *P. m. bairdii* in autumn. The effects of roadside planting and mowing on the abundance of various species of small mammals were attributed to differences in height and density of vegetation and depth and coverage of litter.

Roadside vegetation in intensively farmed regions of the Midwestern United States is traditionally maintained for traffic safety, noxious weed control, and aesthetic appearance by planting of exotic seed mixtures and by frequent mowing (two or more times a year). Roadsides in the region also have been managed to provide nesting cover for ring-necked pheasants by planting selected grass and legume species and by delaying roadside mowing until midsummer when most nesting is complete (1,2,3,4). Although roadsides typically are the only permanent grassland habitat available to small mammals in intensively farmed areas, relationships between small mammal abundance and vegetative characteristics of roadsides have not been documented. The objective of our study was to determine abundance and habitat relationships of small mammal species in roadsides maintained by traditional practices and those managed to provide nesting cover for ring-necked pheasants in south central Minnesota.

Materials and Methods

Study Area

The study was conducted in roadsides along a 35km segment of State Highway (SH) 60 between St. James and 6.5km west of Lake Crystal, and along a segment of Fieldon Township Road (TR) 109 extending 0.8km south from its intersection with SH 60 in Watonwan and Blue Earth Counties in south central Minnesota. This sector of south central Minnesota contained roadsides managed by the Minnesota Department of Natural Resources (MDNR) for ring-necked pheasant nesting cover and roadsides managed traditionally by local landowners or by state and county personnel. The MDNR implemented a roadside mowing and planting program entitled "Operation Pheasant" in 1975 and 1976 to establish pheasant nesting cover along roadsides west of the intersection of SH 60 and SH 15. These roadsides were divided into 1.6km sections, and every fourth section of the roadside was mowed each year after July 30 and then was closed to mowing for the following three years. This mowing pattern proceeded so that each section of the highway was mowed one out of every four years. The remaining roadsides were managed by landowners, who mowed prior to July 30, or by state and county transportation departments, who mowed annually in late summer or autumn if uncut by landowners.

Roadsides along SH 60 southwest of its intersection with Watonwan County Road (CR) 13 were seeded to alfalfa (*Medicago sativa*) and smooth brome (*Bromus inermis*) in 1975 and 1976 by MDNR to provide pheasant nesting cover (planted sites). Roadsides located northeast of the intersection of SH 60 and CR 13 and along TR 109 (unplanted sites) were not seeded since 1971 and were dominated by birdsfoot trefoil (*Lotus corniculatus*). Both planted and unplanted sites typically had a moist center zone dominated by cool-season grasses (*Poa pratensis* and *Phalaris arundinacea*), sedges (*Carex* spp.), and smartweeds (*Polygonum* spp.) and a dry slope zone to each side of the center zone that was dominated by warm-season grasses (*B. inermis* and *Agropyron repens*) and legumes (*M. sativa* or *L. corniculatus*).

Field procedures

Twenty-four study sites, each 250m long, were established in roadsides on the study area, providing three replicates of each of eight roadside treatments (Table 1). These eight treatments were combinations of four roadside conditions: 1) roadside planting: planted (roadsides seeded to *M. sativa* and *B. inermis*) versus unplanted (roadsides not seeded

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for $\geq$ 10 years); 2) roadside mowing: mowed (roadsides mowed during a year of study) versus unmowed (roadsides not mowed during the spring or summer of the year of study); 3) wooded habitat proximity: wooded (roadsides $\leq$ 250m from a shelterbelt, windbreak, or woodlot) versus nonwooded (roadsides > 250m from wooded habitats); and 4) roadside width: narrow (roadsides < 11m wide), medium (roadsides from 11 to 26 m wide), or wide (roadsides > 40m wide). Sites representing other combinations of roadside conditions were not available on the study area. When possible, replicate study sites within roadside conditions were separated by at least 0.5km.

Table 1. Roadside conditions for study sites in south central Minnesota. Codes for conditions are as follows: first character: P = planted, U = unplanted; second character, M = mowed, U = unmowed; third character, W = wooded, N = nonwooded; and fourth character, W = wide, M = medium, N = narrow.

Code	Combinations of Roadside Conditions
PMWM	planted, mowed, wooded, medium
PMNM	planted, mowed, nonwooded, medium
PUWM	planted, unmowed, wooded, medium
PUNM	planted, unmowed, nonwooded, medium
PUNW	planted, unmowed, nonwooded, wide
UMNM	unplanted, mowed, nonwooded, medium
UUNM	unplanted, unmowed, nonwooded, medium
UUNN	unplanted unmowed, nonwooded, narrow

In each study site, 25 live traps (8 x 8 x 26 cm; Tomahawk Live Trap Co., Tomahawk, Wis.) were alternately placed in the flat center zone and in the slope zone at 10m intervals. Rolled oats and peanut butter were used as bait. Traps were set at each site for two consecutive days (a session) every two weeks from August through October in 1980 and 1981, giving six sessions and 300 trap nights per site each year. Small mammal species studied were northern short-tailed shrews (*Blarina brevicauda*), masked shrews (*Sorex cinereus*), prairie deer mice (*Peromyscus maniculatus bairdii*), white-footed mice (*Peromyscus leucopus*), house mice (*Mus musculus*), grasshopper mice (*Onychomys leucogaster*), meadow voles (*Microtus pennsylvanicus*), 13-lined ground squirrels (*Spermophilus tridecemlineatus*), and ermine (*Mustela erminea*). Sex (except for soricids), age, weight, and reproductive condition were recorded at each capture. Individuals were either toe-clipped or marked with numbered eartags (#1, National Band and Tag Co., Newport, Ky.) for identification.

Twenty-two roadside characteristics (Table 2) were quantified in each study site. Sampling points were located at 1m intervals along randomly selected transects extending from road edge to adjacent field edge. Transects were established in a study site until the number of sampling points approximated 100. In sites $\geq$ 40m wide, the interval along a transect was increased to 3m, so that at least four transects could be sampled per site.

Data analyses

The total number of individuals trapped per site was used as an index of abundance for each species. Associations between small mammal abundance and roadside characteristics were tested by product-moment correlations (r); data were transformed (square root, arcsine square root, logarithmic) if necessary to meet assumptions of the test (6). A significant correlation was $r \geq 0.404$ with 22 degrees of freedom and $p < 0.05$.

Abundance of individual small mammal species in relationship to the four roadside conditions was evaluated by G^2 tests of goodness-of-fit and by two- to four-factor tests of independence (7). Year of study was included as a factor in all tests of independence. Month of study (August, September, October) also was included as a factor in tests of independence with fewer than 20% of the cells having expected frequencies < 5. Planting and mowing effects were tested jointly using abundance indices from all medium-width sites. Effects of proximity to wooded habitat and mowing also were tested jointly using abundance indices for planted, medium-width sites. Effects of roadside width were evaluated through comparisons of abundance indices between narrow and medium-width unplanted, unmowed sites, and between wide and medium-width planted, unmowed sites. Other combinations of roadside conditions were not tested because of the fractional design of the study (Table 1). A significant difference in abundance of a small mammal species with a given roadside condition was $p < 0.05$.

Results

Capture frequencies

In 1980, 799 individual small mammals were captured a total of 969 times; in 1981, 1,294 individuals were trapped a total of 1,411 times. Abundance indices for three of eight small mammal species differed significantly between 1980 and 1981 (Table 3).

Habitat associations

At least two *Blarina brevicauda* were captured in each study site per year. *Blarina* was most abundant in an unplanted, unmowed, nonwooded, medium (UUNM) (Table 1) site (23 individuals) with a dense growth of *L. corniculatus* on the slope zone during 1980 and in a planted site (71 individuals) with a dense stand of *M. sativa* on the slope zone during 1981. In both 1980 and 1981, abundance of *Blarina* was positively correlated with total litter coverage, center litter coverage, and forb coverage. In 1981, abundance of *Blarina* also was directly correlated with total aerial coverage, center aerial coverage, total stem density, and slope stem density.

Sorex cinereus was present in 22 of the 24 sites during both years. *Sorex* was trapped most frequently in a planted, mowed, nonwooded, medium (PMNM) site (nine individuals) in 1980 and in an unplanted, unmowed nonwooded, narrow (UUNN) site (seven individuals) with a center zone dominated by tall grass or grass-like species (*Carex* spp., *Andropogon gerardi, Spartina pectinata*) in 1981. Abundance of *Sorex* was positively associated with total, center, and slope vegetation heights in 1981. In more than one-half of the 1981 trapping sessions, more *Sorex* were captured in sites containing standing water than in drier sites.

Unlike other species, *Peromyscus maniculatus bairdii* was associated with different roadside characteristics in summer and early fall. During August 1980 and 1981, abundance of *P. m. bairdii* was negatively correlated with all vegetation height variables; in August 1981, abundance was positively correlated with slope litter depth. Abundance of *P. m. bairdii* in September was negatively correlated with center litter depth during both years and with aerial coverage variables and litter coverage variables in 1980. In 1980 and 1981, abundance of *P. m. bairdii* in October was negatively related to aerial coverage variables, center litter coverage, and total stem density. Abundance of *P. m. bairdii* in October also

Table 2. Description of roadside characteristics measured at 24 study sites in south central Minnesota.

Characteristic Name	Description
Vegetation height	mean maximum vegetation height (cm) in a 15cm radius plot centered on each sampling point.
Center vegetation height	mean maximum vegetation height (cm) in a 15cm radius plot centered on each center zone sampling point.
Slope vegetation height	mean maximum vegetation height (cm) in a 15cm radius plot centered on each slope zone sampling point.
Litter depth	mean litter depth (cm) at a sampling point.
Center litter depth	mean litter depth (cm) at a center zone sampling point.
Slope litter depth	mean litter depth (cm) at a slope zone sampling point.
Aerial vegetation	proportion of total sampling points with standing vegetation directly overhead.
Center aerial vegetation	proportion of center zone sampling points with standing vegetation directly overhead.
Litter coverage	proportion of total sampling points covered by litter.
Center litter coverage	proportion of center zone sampling points covered by litter.
Grass coverage	proportion of a 15cm radius plot centered on each sampling point dominated by grasses or grass-like species.
Forb coverage	proportion of a 15cm radius plot centered on each sampling point dominated by forbs (non-grass or grasslike herbaceous vegetation).
Stem density	mean number of stems in a 5cm radius of every other sampling point at 2cm above soil level.
Center stem density	mean number of stems in a 5cm radius of every other center zone sampling point at 2cm above soil level.
Slope stem density	mean number of stems in a 5cm radius of every other slope zone sampling point at 2cm above soil level.
Slope stem density	mean number of stems in a 5cm radius of every other slope zone sampling point at 2cm above soil level.
Grass density	mean number of grass or grass-like (i.e., sedges) stems in a 5cm radius of every other sampling point at 2cm above soil level.
Center grass density	mean number of grass or grass-like stems in a 5cm radius of every other center zone sampling point at 2cm above soil level.
Slope grass density	mean number of grass or grass-like stems in a 5cm radius of every other slope zone sampling point at 2cm above soil level.
Forb density	mean number of forb stems in a 5cm radius of every other sampling point at 2cm above soil level.
Center forb density	mean number of forb stems in a 5cm radius of every other center zone sampling point at 2cm above soil level.
Slope forb density	mean number of forb stems in a 5cm radius of every other slope zone sampling point at 2cm above soil level.
Wooded border length	length (m) of border of site with a woodlot, windbreak, or shelterbelt.

was negatively correlated with center litter depth during 1980 and with total litter depth in 1981. Abundance of *P. m. bairdii* correlated with vegetation height variables in October 1981.

All 77 *Peromyscus leucopus* captured in 1981 were trapped in sites with adjacent wooded habitats. Only five of the 27 *P. leucopus* captured in 1980 were trapped in roadsides not bordering wooded areas; all five individuals were males and four were subadults.

Mus musculus was trapped in 11 sites during 1980 and in 16 sites during 1981. Abundance of *Mus* was negatively correlated with total and slope vegetation heights and was positively correlated with center aerial coverage during both years. In 1980, abundance of *Mus* was directly related to slope litter depth.

Microtus pennsylvanicus was captured in 22 sites in 1980 and in 23 sites in 1981. Abundance of *Microtus* in 1980 was positively correlated with total litter depth, total litter coverage, center aerial coverage, total stem density, and center grass density. In 1981, abundance of *Microtus* was negatively related to center vegetation height. *Microtus* were significantly more abundant, and reproduction and number of young appeared to be higher in 1981 than in 1980. The proportion of adult female *Microtus* ($\geq$ 30g) that were lactating was greater in 1981 than in 1980 (69% vs 43%; goodness-of-fit test: $G^2 = 5.29$, df = 1, $p = 0.02$), and immature *Microtus* ($<$ 30g) represented a larger proportion of the meadow voles captured in 1981 than in 1980 (74% vs. 58%; $G^2 = 12.7$, df = 1, $p < 0.001$). Immature voles had a lower recapture rate than adults (2.5% vs. 14.3%; $G^2 = 15.4$, df = 1, $p < 0.001$). Both center stem and center grass densities were greater in 1981 than in 1980 (single-classification analyses of variance; $Fs = 7.4$ and 5.9; df = 1,32; $ps \geq 0.02$) (5). A greater density of *P. pratensis* in roadsides during 1981 than 1980 ($F = 4.4$; df =1,32; $p = 0.04$) was largely responsible for the differences in center stem densities between years.

During 1980, both the number of resident adult *Microtus* (individuals $\geq$ 30g trapped in the same site during at least two trapping sessions) and the number of immature *Microtus* was positively correlated to center stem density. During 1981, abundance of resident adult *Microtus* was positively related to total litter depth, whereas abundance of immature *Microtus* was negatively related to all vegetation height variables.

Mustela erminea was captured in 13 and 14 sites in 1980 and 1981, respectively. Abundance of *Mustela* was positively correlated with all vegetation height variables during both years and was also negatively related to all grass density variables in 1980.

Effects of roadside conditions

Roadside mowing had a negative effect on abundance of *Blarina*. However, mowing had less effect on abundance of *Blarina* in planted than in unplanted sites, and the mowing effect was significant only among unplanted sites in 1981.

Table 3. Number of individuals of each mammal species captured in eight combinations of roadside conditions (summed over replicate sites within combinations) in south central Minnesota roadsides from August through October in 1980 and 1981. Combinations of roadside conditions and codes are given in Table 1. Asterisks indicate significant differences in total number of captives per species between years; *$p \leq 0.05$

		Code for the Combinations of Roadside Conditions								
Species	Year	PMWM	PMNM	PUWM	PUNM	PUNW	UMNM	UUNM	UUNN	Total
Blarina	1980	37	28	47	40	22	32	45	17	268*
brevicauda	1981	62	99	78	53	23	56	66	19	456
Sorex	1980	5	16	5	8	5	9	14	15	77
cinereus	1981	3	5	14	8	11	7	6	15	69
Peromyscus	1980	49	24	20	52	42	19	6	26	238
maniculatus bairdii	1981	39	47	31	40	52	11	12	28	260
Peromyscus	1980	7	1	15	0	0	1	1	2	27*
leucopus	1981	8	0	69	0	0	0	0	0	77
Mus	1980	14	9	0	0	2	4	2	2	33
musculus	1981	14	12	2	0	4	5	7	4	48
Microtus	1980	34	8	10	13	13	35	21	20	154*
pennsylvanicus	1981	58	57	36	56	45	67	57	7	383
Mustela	1980	1	0	6	9	5	0	4	2	27
erminea	1981	0	4	1	3	6	2	9	7	32

Mowing also had an negative overall effect ($p < 0.05$) on abundance of *Sorex*, but this effect differed between planted and unplanted sites. The interaction of mowing and planting practices also differed between years. During 1980, roadside mowing had a significant negative impact on abundance of *Sorex* in unplanted roadsides but not in planted roadsides. In 1981, abundance of *Sorex* was reduced by mowing in both planted and unplanted roadsides, and the mowing effect was not significantly dependent on planting practices.

P. m. bairdii was significantly more abundant in planted sites than in unplanted sites. However, during August and September, *P. m. bairdii* was more abundant in planted sites than in unplanted sites in both mowed and unmowed roadsides. In October, planting practices were significant only in unmowed sites.

Roadside mowing had a positive effect on abundance of *P. m. bairdii* in August in both planted and unplanted sites. In contrast, mowing reduced the number of *P. m. bairdii* in unplanted sites in September but did not significantly influence abundance in planted sites during that month. Abundance of *P. m. bairdii* in October was reduced by mowing in both planted and unplanted sites.

Roadside mowing had a negative effect on the abundance of *P. leucopus* near wooded sites. Mowing had a positive influence on abundance of *Mus* in planted sites, whereas equal numbers of *Mus* were captured in mowed and unmowed sites which were unplanted. Mowing had negative overall effects on abundance of both *Microtus* and *Mustela*; however, the mowing effect on *Microtus* was significant only in planted sites.

The effect of planting practices on abundance of *Microtus* differed between years. In 1980, unplanted sites contained more *Microtus* than planted sites in both mowed and unmowed roadsides. In unmowed roadsides, *Microtus* were more numerous in planted than in unplanted sites in 1981. Further, *Microtus* were less numerous in narrow sites than in similar medium-width sites in 1981.

Discussion

Getz (8) concluded that *Blarina* preferred moist habitats and avoided sparsely vegetated areas because of a need for humid microhabitats. The high evaporative rate of *Blarina* (9) could be responsible for positive relationships between abundance of this species and litter coverage, forb dominance, and stem densities. Because *Blarina* makes extensive use of runways in moist litter layers, extent of litter coverage may be an important factor in determining roadside use by this soricid. In sites where forb coverage was high, dense growth of either *L. corniculatus* or *M. sativa* on slope zones provided almost complete aerial coverage a few centimeters above ground level, thereby maintaining high humidity and soil moisture. Roadside mowing, on the other hand, probably decreased abundance of *Blarina* by reducing the amount of vegetative cover and, consequently, reducing ground level humidity. In contrast, Wrigley et al (10) and Yahner (11) reported that vegetative cover was not an important factor determining microhabitat use by *Blarina*. However, their studies were in wooded and marsh habitats where ground-level microhabitats were probably more mesic than those in open, herbaceous roadside habitats of south central Minnesota.

S. cinereus is associated with mesic or hydric areas, and type of vegetation or amount of cover do not have a major influence on the distribution of the species (7,10,12). In our study, the correlation between abundance of *Sorex* and vegetation height in 1981 presumably resulted from a greater density of tall grass or grass-like species growing in wetter soils. Because roadsides with standing water for prolonged periods often had slopes that were too steep to permit haying by landowners, differences in abundance of *Sorex* between mowed and unmowed sites may have resulted from less frequent mowing of wet roadsides.

Seasonal shifts in habitat associations by *P. m. bairdii* may be explained by seasonal changes in food supply. Roadside mowing is a localized disturbance making seeds of annual grasses available to rodents in summer prior to natural seed release. Additionally, mowing may increase the local abundance of some herbivorous invertebrates by delaying maturation and seasonal die-back of roadside vegetation and by producing clumps of debris to shelter invertebrates. Thus, during summer, mowed sites may contain greater quantities of seeds and invertebrates, which are two important food resources of *P. m. bairdii* (13,14). In autumn, seeds become relatively more available in unmowed sites as graminoid inflorescences mature and release seeds. This was particularly true in planted, unmowed sites where *B. inermis* dropped much of its seed crop over a period of a few weeks in early autumn. Adjacent cultivated crops probably had little influence on the distribution of *P. m. bairdii* in roadsides because consumption of corn and soybeans is lowest during summer and autumn before harvest (14).

The affinity of *P. leucopus* for shrubby and wooded habitats is well documentd (11,15,16). Additionally, Sadleir (17), Savidge (18), and Hansen and Batzli (19) indicated that *Peromyscus* populations may be regulated by dispersal and mortality of immature individuals resulting from adult aggression. Immature *P. leucopus* captured in nonwooded roadsides may have dispersed from wooded habitats as a result of such behavior.

Mus did not shift habitats between late summer and autumn as did *P. m. bairdii*, despite similar diets (13,14). This seasonally stable distribution of *Mus* in roadsides was in contrast to the pattern seen for *Mus* populations in corn, wheat, and hay fields, where movements occurred between fields in response to crop maturation and harvest (20). Use of mowed sites in autumn by *Mus* suggests that factors other than food availability may have influenced its use of roadside habitats.

Vegetative densities were lower in 1980 than 1981 as a result of reduced vigor of dense growing cool-season grasses, such as *P. pratensis*, during the hot, dry spring and summer of 1980 (5). The positive association between *Microtus* abundance and vegetative densities in 1980 suggests that sparse grasses limited vole abundance, whereas the density of grass cover in the wetter 1981 may not have been an important factor affecting the abundance of *Microtus*. Thompson (21) and Zimmerman (22) also noted positive associations of *M. pennsylvanicus* with dense grasses, particularly *Poa* spp. Stickel and Warbach (23) and Getz (24) have shown a positive relationship between *Microtus* densities and quantity of grass cover. Roadside mowing may have a negative effect on abundance of *Microtus* in roadsides planted with warm-season grasses, such as *B. inermis*, which provide lower stem densities at ground level than do cool-season grasses.

Simms (25) suggested that use of grasslands by *M. erminea* may be affected by vole abundance, and Erlinge (26) concluded that the abundance of *M. nivalis* in Sweden was related to abundance of small rodents. However, abundance of *M. erminea* in south central Minnesota roadsides was not correlated with those of other small mammals (5).

Craighead and Craighead (27) and Powell (28) suggested that raptors consumed about 70% of spring weasel populations in Lower Michigan. The association of *Mustela* with sites characterized by tall vegetation in roadsides during both years may have reduced the ability of raptors perching on nearby telephone and electric wires to detect weasels.

In summary, abundance of *Blarina, Microtus, Mus, Mustela,* and both species of *Peromyscus* differed between roadsides managed by MDNR and those managed traditionally. Effects of roadside planting and mowing practices on abundance of small mammals may be attibuted primarily to the resulting height and density of vegetation and depth and coverage of litter.

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